NAG 5-71

ON THE PROGENITORS OF WHITE DWARFS[1]

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(NASA-CR-174378) ON THE PROGENITORS OF WHITE DWARFS (Louisiana State Univ.) 11 p HC A02/MF A01 CSCL 03A

N85-18913

Unclas

G3/89 14168

[1]Contributions of the Louisiana State University Observatory No. 000.

ABSTRACT

Direct observational evidence is presented which indicates that the immediate progenitors of white dwarfs are the central stars of planetary nebulae (~70%), other post-AGB objects (~30%), and post-HB objects not massive enough to climb the AGB (~0.3%). The combined birth rate for these objects (2-3 x 10^{-12} pc^{-3} yr^{-1}) is in satisfactory agreement with the death rate of main-sequence stars and the birth rate of white dwarfs.

Weidemann (1977) has pointed out that the birth rates for white dwarfs and central stars of planetary nebulae (CPN) are very similar, implying that the immediate progenitors of white dwarfs are CPN. We know, however, that some white dwarfs must be descended from the subdwarf O and B stars discussed by Hunger and Kudritzki (1981), which are apparently helium-shell-burning objects which have evolved from the horizontal branch (HB), but do not have enough mass to ascend the asymptotic giant branch (AGB) and become CPN. Unfortunately, the distances, and hence the space densities, of these objects are not known, so that we cannot determine the relative importance of this channel to white dwarfhood as compared to the CPN.

Drilling (1983) has identified 12 objects which Schönberner and Drilling (1984) have found to occupy a region in the H-R diagram between the sdO stars of Hunger and Kudritzki (1981) and the hottest white dwarfs. Schönberner and Drilling (1984) determined the color excesses and effective temperatures of these stars from IUE observations and UBV photometry, and because $|b| < 25°$ in all cases, the distances could be estimated from the color excesses. The distances are in all cases consistent with the luminosities indicated by the appearance of the visible spectrum (Drilling 1983). These stars form a complete sample to $B \sim 12.5$ for $|b| < 10°$, and for $|b| < 30°$ in the longitude range $-60° < l < 60°$, as it was obtained by observing at moderate spectroscopic resolution all objects within these limits which show a nearly continuous spectrum on objective-prism plates (a total of 1100 stars). That such objects have not been picked up in surveys at high galactic latitude indicates that they have a galactic distribution similar to the CPN, and three of the objects have, in fact, been subsequently found to possess planetary nebulae of low surface brightness.

In Table 1, we have divided these stars into three groups on the basis of their positions in the H-R diagram as determined from Fig. 4 of Schönberner and Drilling (1984). Group 1 contains objects which lie on the theoretical evolutionary tracks of Schönberner (1979, 1981, 1983) for post-AGB stars which evolve fast enough to illuminate planetary nebulae produced on the AGB before the nebulae have dispersed. Inspection of the ESO-SRC Sky Survey (J) prints has, in fact, revealed planetary nebulae around all three of these stars. Because these nebulae are all southern hemisphere objects of low surface brightness, they have not been detected previously. Group 2 contains those objects which lie on the tracks for post-AGB stars which do not evolve fast enough to illuminate nebulae ejected on the AGB, and none of these objects have been found to possess planetary nebulae. None of the objects in Group 2 are He-rich, in accordance with the evolutionary calculations, which show them to be powered mainly by hydrogen-shell burning. Group 3 contains stars which lie to the right of the least massive post-AGB track possible (~ 0.55 M_0). Such objects lie on or near the evolutionary tracks to be expected for stars evolving from the HB which are not massive enough to climb the AGB (~ 0.5 M_0). Since these stars are not powered by hydrogen-burning, it is possible for them to have helium-rich atmospheres, and this is indeed the case for those four objects which have the lowest surface gravities.

We have estimated the space densities of these three groups by dividing the number of stars in each by that volume defined by a) the area of the sky covered by Drilling's survey and b) the distance of a star with B = 12.5 and an absolute magnitude equal to the median for the group (the interstellar absorption was taken to be A_B = 1.7 magn/kpc in this

calculation). We then divided the space densities by the corresponding evolutionary times to obtain the birth rates for these three types of objects. For Groups 1 and 2, the evolutionary times were obtained from Schönberner's (1981, 1983) calculations. They are the times required for post-AGB stars of 0.58 and 0.55 $M_{\odot}$, respectively, to evolve from an effective temperature of 40,000 K to a point where the luminosity has decreased by a factor of 3. For Group 3 we have used the time required for helium-shell burning according to Paczynski's (1971) calculation for a 0.5 $M_{\odot}$ pure helium star.

Because all theoretical evolutionary tracks leading from the main sequence to the white dwarf state pass through the locus of either groups 1, 2, or 3 in the H-R diagram, we must have

$$b_{WD} = b_1 + b_2 + b_3 = d_{MS}$$

where b_{WD} is the birth rate for white dwarfs; d_{MS} is the death rate for main-sequence stars; and b_1, b_2 and b_3 are the birth rates for the three groups of white dwarf progenitors given in Table 1[1]. The best value

[1]We assume that the birthrates of neutron stars and black holes are negligible compared to that of white dwarfs.

obtained to date for b_{WD} is 1.4×10^{-12} pc^{-3} yr^{-1} (Green 1977), and for d_{MS} it is 2.5×10^{-12} pc^{-3} yr^{-1} (Cahn and Wyatt 1976). The value given by Weidemann (1977) for b_1 (1.8×10^{-12} pc^{-3} yr^{-1}), which is based on the work of Cahn and Wyatt (1976), is probably better than the value given in Table

1, because the sample of Cahn and Wyatt is much larger[2].

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[2]Note that although the birth rate for PN given in Table 1 is very similar to that derived from the sample of Cahn and Wyatt, the space density is smaller. This is because our sample contains only objects with $B < 12.5$ which are nearer than 700 pc, i.e., intrinsically bright central stars.

If we assume that the value given by Weidemann (1977) for b_1 is without error and that the random errors in the absolute magnitudes given by Schönberner and Drilling (1984) can be as large as ±2.4 (a factor of 3 in the distance), we can draw the following conclusions: (1) the majority (30-95%) of white dwarfs are descended from stars which at one time were surrounded by observable planetary nebulae; (2) a significant fraction of white dwarfs (5-70%) are descended from post-AGB stars which did not evolve fast enough to illuminate planetary nebulae ejected on the AGB; (3) only a very small fraction of white dwarfs (0.1-2%) are descended from objects which were not massive enough to climb the AGB; and (4) the combined birth rate for all white dwarf progenitors ($2\text{-}3 \times 10^{-12}$ stars/pc^3/year) is in satisfactory agreement with both the birth rate of white dwarfs and the death rate of main sequence stars to within the observational errors, i.e. the above equation is satisfied. Systematic errors in the distances can affect the last conclusion, but not the other three, as they are based only on relative distances.

These conclusions are in good agreement with the mass distribution derived by Weidemann and Koester (1984) for DA white dwarfs. According to them, ~40% of the DA white dwarfs have masses less than 0.55 $M_\odot$, which is the minimum mass of a central star with an observable planetary nebulae

according to Schönberner (1983). Because of the small number of objects included in Table 1, it would be desirable to extend Drilling's (1983) survey to the same limiting magnitude as the existing surveys for planetary nebulae. Since the objects involved have absolute magnitudes and space distributions similar to those of central stars, this cannot be done by surveying at high galactic latitude, but must rather be done at $|b| < 20°$.

ACKNOWLEDGEMENTS

We are greatly indebted to Prof. V. Weidemann, who urged us to make the above study. This work was supported in part by NSF grant nos. AST 8018766 and INT 8219240, and by NASA grant no. NAG 5-71, and was carried out while one of us (JSD) was on a sabbatical at the Institut für Theoretische Physik und Sternwarte der Universität Kiel.

TABLE 1

BIRTH RATES FOR WHITE DWARF PROGENITORS

	No. of Stars	Space Density (stars/pc^3)	Evolutionary Time (yr)	Birth Rate (stars/pc^3/yr)
Group 1	3	1.1×10^{-8}	1×10^{4}	1×10^{-12}
Group 2	3	1.2×10^{-7}	2×10^{5}	6×10^{-13}
Group 3	6	1.6×10^{-7}	2×10^{7}	8×10^{-15}

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